Ask Dr. ALOHA:

**A Footprint
Anatomy Lesson**

Alice Chen, the assistant safety manager at a Midwestern ammonia storage facility, has just received a copy of ALOHA that she wishes to use to model potential ammonia releases. She has already performed a hazard evaluation of her facility and determined that one of the most likely accidents could be a valve leak at the base of one of the large ammonia storage spheres at the facility.

A release scenario

She uses ALOHA to model a leak from a 2-inch valve at the base of a storage sphere. The tank is 20 feet in diameter and contains 60 tons of liquid ammonia stored at an ambient air temperature of 85°F. Wind speed is about 6 knots at a height of 3 meters (10 feet), the sky is 50 percent covered by clouds, there is no inversion, humidity is about 60 percent and the area adjacent to the facility is mostly open farming country.

Alice obtains a footprint plot, showing the area downwind of the release where a hazard to people may exist. She finds that depending on the circumstances of the release and the toxic threshold that she uses as her level of concern, the hazard zone might extend into some of the neighborhoods closest to her facility.

As she thinks about this potential accident, she realizes that responders would surely be exposed to the highest ammonia gas concentrations as they approached the leaking valve in order to close off the leak.   How high might gas concentrations be in the immediate vicinity of the release? Alice next decides to use ALOHA to check concentration at a location about 10 feet downwind of the leaking valve. To do this, she chooses **Concentration...** from the **Display** menu, then enters the coordinates of a location 10 feet downwind from the release point and directly on the cloud centerline.

She knows that ALOHA can display a plot of the concentration of ammonia gas in the air at the location she has chosen, for the hour following the start of the release. But the information that she sees in ALOHA's Concentration Window, shown in Figure 1 below, surprises her. (Note: Alice is using ALOHA 5.2; the Concentration graph produced by ALOHA 5.1 for this scenario looks slightly different.)

First, the concentration values that she sees along the vertical axis of the plot are not in the decimal notation that is most familiar to us. (Some examples of numbers in decimal notation are 100, 12.3, 0.012, and 3.) Instead, she sees expressions such as "1.5e+06" and "2e+06." This notation does look a bit familiar to her, though; she checks some of her old college mathematics texts to refresh her memory.
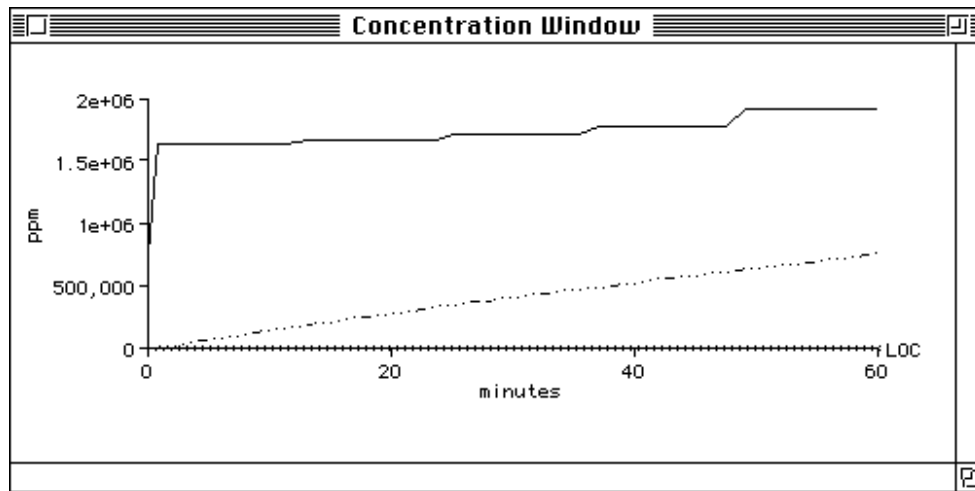
Figure 1. ALOHA's Concentration Window for an ammonia release, with some concentration values in exponential notation.

ALOHA uses exponential notation

Alice discovers that ALOHA displays its results in **exponential notation** whenever numbers are too large to display in decimal notation (it also accepts numerical input in exponential form). Exponential notation is a way of displaying a number as a digital number multiplied by a power of 10. In the number 5e3, for example, 5 is the digital number and 3 is the power to which 10 is taken. Interpret 5e3 or 5e+3 as "5 times the quantity 10 taken to the power of 3," which equals 5,000 in decimal notation. Likewise, interpret 5e-3 as "5 times the quantity 10 taken to the power of -3," which equals 0.005 in decimal notation. Interpret 1.5e6 or 1.5+e6 as "1.5 times 10 taken to the power of 6," or 1,500,000.

ALOHA is not a near-field model

The second surprise to Alice is that the values she sees in the Concentration Window don't make sense to her. ALOHA reports that the ammonia gas concentration 10 feet downwind from the release point may rise to about "2e+06" by the end of the hour. This value can be interpreted as 2 times 10 taken to the power of 6, which equals 2,000,000, or two million. But the units of concentration are parts per million (ppm). If every molecule in the air at a location is a molecule of ammonia, then the ammonia concentration is at a maximum of one million parts per million. How could concentration ever be higher than that? Alice calls CAMEO Technical Support to ask whether she's found a bug in the program.

The technical support staff have a ready answer because other observant ALOHA users have asked this question in the past. Very near the source point, they explain, ALOHA's results are not useful. ALOHA "knows" that concentrations of a pollutant can be extremely high right at the point of release, and drop off as you move downwind. It uses equations to approximate what happens in reality. ALOHA's equations much more accurately predict events at

distances of more than a few yards from the source than very near the source, within the region that researchers call the **near-field**. According to ALOHA's equations, in fact, concentration is infinite at the point of release, although this can never happen in reality. You may have noticed that ALOHA will not plot a footprint if the distance to your level of concern is less than 100 meters (109 yards). This cutoff exists because ALOHA's developers are aware of the inaccuracy of its calculations for the near-field. Although ALOHA allows you to see the results of its concentration calculations for any distance downwind, remember its limitations and disregard its concentration estimates for locations very close to the source.

The footprint represents an average view

Technical Support goes on to explain a related point: No one can predict gas concentrations at any particular instant downwind of a release, because they result partly from random wind eddies. Instead, ALOHA shows you concentrations that represent averages for time periods of several minutes (it uses statisticians' knowledge of the laws of probability, meteorologists' knowledge of the atmosphere, and physicists' knowledge of the behavior of gases to do this). ALOHA predicts that average concentrations will be highest near the release point and along the centerline of any pollutant cloud, and will drop off smoothly and gradually in the downwind and crosswind directions. However, especially near the source of a release, wind eddies push a cloud unpredictably about, causing gas concentrations at any moment to be high in one location and low in another. Although concentrations are more likely, on average, to be high near the centerline and not far downwind, concentrations at a particular instant may be distributed very differently. As the cloud moves downwind from the release point, eddies shift and spread the cloud, evening out concentrations within the cloud so that well downwind they become more similar to ALOHA's predictions.

ALOHA's footprint is called an **ensemble average** depiction of a cloud because it represents the area within which, at any particular location, average chemical concentration may exceed the level of concern*at some time* after the start of a release rather than at any particular time. Don't confuse the footprint with an instantaneous, or "snapshot," view of the toxic cloud at any particular moment. Figure 2 depicts both ALOHA's footprint and an instantaneous view of a chemical cloud that is dispersing from a continuous source such as an evaporating puddle or slowly leaking gas tank. At the instant depicted by this figure, the cloud is dispersing approximately along the centerline of the footprint. At another instant, the wind may switch direction to push the cloud towards either edge of the footprint. Wind eddies may cause the cloud to bend and curve as it moves. Over time, the cloud will have switched back and forth within the entire area enclosed by the footprint.
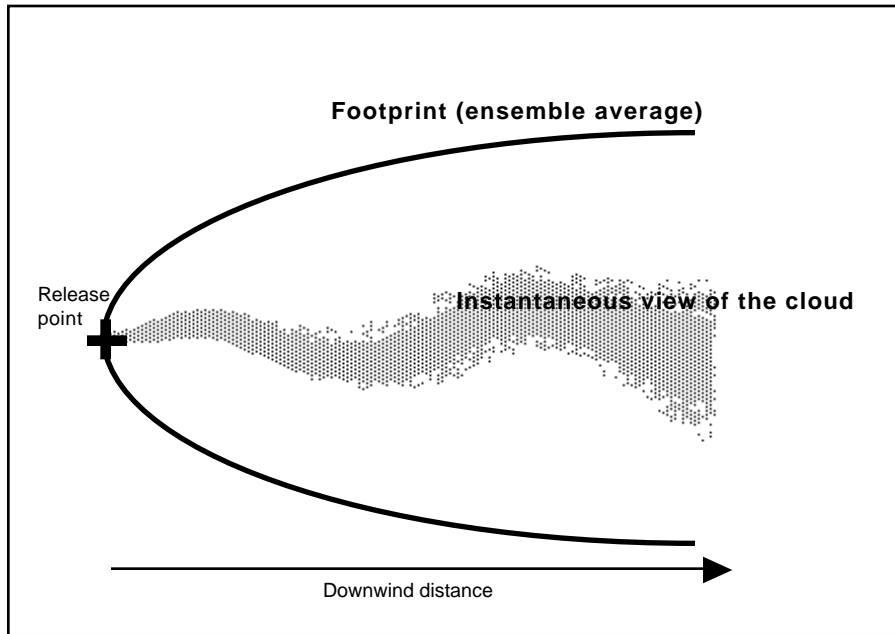
Figure 2. Ensemble average and instantaneous views of a toxic gas cloud.

As Alice hangs up her telephone, she mentally reviews her conversation with Technical Support, realizing that for her, the most important information is this: ALOHA is useful for predicting hazard to people within an area up to a few miles from a release. However, its Concentration graph is not a good tool for predicting the hazard to people working next to a leaking storage vessel or evaporating toxic pool. (But you may wish to use ALOHA's Source Strength graph and/or its estimate of ambient saturation concentration to learn more about the amount of chemical leaking or evaporating from a source and the maximum concentration that the chemical could reach in the air near an evaporating pool.) Also, ALOHA can't predict the exact location of a toxic cloud at a particular moment, although it can display the area where, over time, the chemical cloud is most likely to be.

Alice plans to continue her work with ALOHA because she needs to assess the hazard that accidents at her facility might pose to nearby populated areas. She hopes to use her ALOHA results as she works with community planners to develop an emergency response plan for her district. But she'll look elsewhere for the information she needs to assess the hazard to people very close to an accident site.

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A mystery scenario
Early on a January morning near the campus of the University of Alaska at Fairbanks, a flatbed truck has slid off an icy road and now rests precariously at the bottom of a steep embankment. Included in the truck's cargo is a filled 1-ton chlorine cylinder bound for the nearby water treatment plant. Mary Schubert, the university's safety manager, runs ALOHA in order to assess the hazard to the campus if the cylinder is damaged when the truck is hauled back onto the roadway. Experience suggests that a leak from the 2-inch valve at the center of one end of the cylinder (which is lying on its side on the bed of the truck) would be the most likely scenario.

The current air temperature is -30°F, but Mary expects the temperature to warm by 3 or 4 degrees during the day. Wind speed is about 6 miles per hour, the sky is clear, the humidity is very low, and ground roughness is Urban or Forest. The cylinder is 2.5 feet in diameter and about 6.8 feet long. Mary runs two ALOHA scenarios for this release, the first at the current temperature and the second at a temperature of -26°F, the likely air temperature by midday. ALOHA's results momentarily surprise her because the footprint plots are quite different, but she soon realizes what the model is telling her. What is the explanation for Mary's results?

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